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A strain gauge

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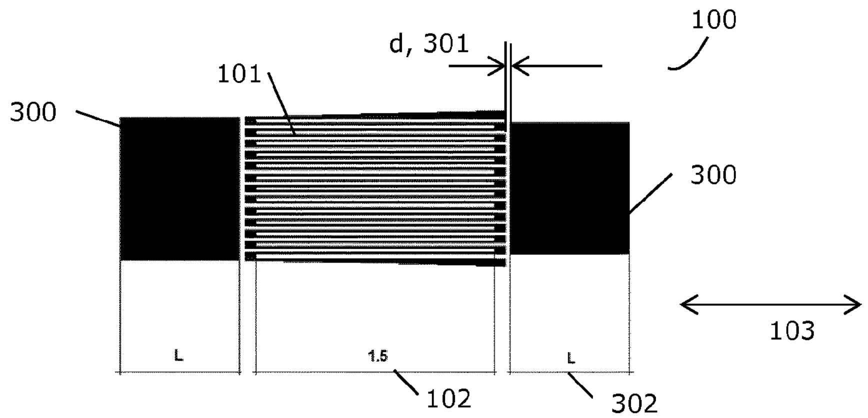


Fig. 3

(57) **Abstract**: The invention relates to a strain gauge of a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the strain gauge comprises two reinforcement members positioned on the carrier layer at opposite ends of the measurement grid in the axial direction. The reinforcement members are each placed within a certain axial distance to the measurement grid with the axial distance being equal to or smaller than a factor times the grid spacing. The invention further relates to a multi-axial strain gauge such as a bi-axial strain gauge or a strain gauge rosette where each of the strain gauges comprises reinforcement members. The invention further relates to a method for manufacturing a strain gauge as mentioned above.

WO 2016/020152 A1

A STRAIN GAUGE

Field of the invention

The present invention relates to a strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer. The invention also relates to multiple strain gauge design such as bi-directional strain gauges and strain gauge rosettes, and to a method of manufacturing these.

Background

Strain gauges are the most widely used strain and deformation measurement devices for metallic materials but are also used extensively for more compliant material such as polymers and polymer matrix composites, and are applied on materials with a stiffness ranging from just some Giga-Pascal (e.g. Polyester with an elasticity module of approximately E = 2.8GPa) to hundreds of Giga-Pascal (e.g. Steel, E =200GPa or UD Carbon fiber composites of E=100-400 GPA).

The application of strain gauges ranges from material characterization of test coupons with geometrical dimensions in several millimetres and centimetres up to deformation measurements on structural components with dimensions of many meters.

A strain gauge in general consists of a metallic grid, which changes its electrical resistance during deformation. In a typical configuration, the out-of-plane thickness of the grid is in the order of approximately 5µm and is most often made of an 180GPa stiff constantan alloy. In applications, the strain gauges are bonded to the test sample surface and the deformation of the test sample is then determined by measuring the changes of the electrical resistance in the strain gauge together with a calibration factor provided by the strain gauge manufacturer.

Uni-axial strain gauge models are commonly used in tests or on equipment for the determination or control of the stiffness of the test specimen or, in general, for the determination of uni-axial strain. Bi-axial 00°/90° gauges are typically utilized for determination of the Poisson's ratio of the material, or, in general for measurements of bi-axial strains at a 90° angle difference. Likewise, bi-axial 45°/-45° gauges are often applied for the determination of Shear Modulus and strain gauge rosettes are used to determine the full plane strain state.

Experience, and literature, however, report evidence of errors or large inaccuracies in measurements performed especially on highly and moderately compliant materials (i.e. a material of lower stiffness). Some experimental studies have reported different determined elastic modulus values for identical polymer matrix based composites when comparing strains measurements from strain gauge with measurements from clip-on extensometers. Such deviations are suspected to be caused by the stiffness mismatch between the strain gauge including a thin metal grid, and the test sample especially when more compliant.

Experimental observations are supported by numerical simulation showing that strains inside a test material are altered significantly when bonding a strain gauge onto the test material surface. The strains locally in the test sample are reduced due to local stiffening where the deformation is constrained just below the strain gauge. Thereby, lower strains are transferred to the strain measuring grid. For sufficiently thick test coupons, the main contribution lowering the measured strain values is believed to arise from edge effects making the testing material deforming more in front of the metal grid and less under the grid. These edge effects are furthermore seen to become more pronounced for shorter strain gauges. This effect is sometimes referred to as the reinforcement effect.

Experimental measurements as well as numerical simulations show that for a strain gauge calibrated for a 200 GPa stiff material, the error on the measured E-modulus is 2-5% for a 10 GPa stiff biax-composite material and 5-15% for a 3 GPa stiff polymer material depending on the strain gauge length, and thus quite significant.

This in-accuracy or error of strain gauge measurements due to the stiffness mismatch between the strain gauge material and the test material may to some extent be reduced by additional calibrations of a conventional strain gauge on a material with the relevant stiffness. Nevertheless, for anisotropic composite material this is not practically possible as the material stiffness is highly dependent on the orientation of the strain gauge on the test sample. As an example a unidirectional glass fiber composite has an axial stiffness of 35-45GPa whereas the stiffness in 45 degree is less than 10GPa. Nevertheless, strain gauges are often used to determine the full stress strain curve of a given material where the strain gauge is calibrated on one single given material with a given fixed stiffness

Also, the use of correction parameters or gauge factors to reduce the in-accuracy or error of the strain gauge measurements on anisotropic and/or nonlinear materials is not effective or practically possible. Because the grid material of the strain gauge shows non-linear effects, a correction parameter or gauge factor should likewise be non-linear to obtain a more accurate stress-strain curve determination. This is however rarely taken into consideration in experimental measurements as the non-linearity of conventional strain gauges is also highly dependent on any non-linearity of the material which is tested and measured. As more compliant materials in general often show significant non-linearity (such as for example polymers), this problem of non-linearity leading to imprecise correction parameters or gauge factors is especially prone for strain gauge measurements on generally nonlinear materials and many anisotropic materials such as reinforced composites.

Nevertheless, strain gauges are used to a great extent as strain identification sensors in composite structures. In addition, the standards often recommend the use of a strain gauge as the most accurate strain measurement device during mechanical testing of polymer matrix composite materials.

Description of the invention

It is therefore an object of embodiments of the present invention to overcome or at least reduce some or all of the above described disadvantages of the known types of strain gauges by providing a strain gauge with improved performance especially when applied on anisotropic materials such as composites.

It is an object of embodiments of the invention to provide a strain gauge which yield more accurate strain or deformation measurements and with no or a reduced dependency of the stiffness or non-linearity of the tested material.

It is a further object of embodiments of the invention to provide a strain gauge which yield more constantly accurate strain or deformation measurements for different types of materials with elasticity moduli ranging from a few to hundreds of GPa such as in the range of 2-400 GPa.

It is a further object of embodiments of the invention to provide a strain gauge with reduced edge or reinforcement effects.

It is a further object of embodiments of the invention to provide a strain gauge which may be manufactured with few or minimal changes to conventional strain gauge manufacturing.

It is a further object of embodiments of the invention to provide a method of manufacturing a more precise or accurate strain gauge.

In accordance with the invention this is obtained by a strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the measurement grid is arranged such as to measure a deformation in an axial direction of the strain gauge. The measurement grid comprises a number of interconnected grid sections placed side by side with gaps in between. The strain gauge further comprises two reinforcement members positioned on the carrier layer at opposite ends of the measurement grid in the axial direction, where the reinforcement members are each placed with an axial distance to the grid with the axial distance being equal to or smaller than a factor times the gap distance, wherein the factor is in the range of 1-5, such as in the range of 1-3, such as approximately 1.

The wire sections are conventionally placed as close as practically possible without touching in order to minimize the resistance changes of the measurement grid caused by other deformations than those in the axial direction which are to be detected and measured. The grid sections may be placed with a wire distance or gaps in between in the range of 0.01-1.00 millimeters such as in the range of 0.02-0.5 millimeters.In general when using a strain gauge, the strain field of the specimen to be measured on is perturbed by the installation of the strain gauge. This effect is most evident when the material on which the gauge is installed is more compliant that the gauge itself and is therefore more evident on e.g. on materials such as Epoxy (Espec = 3GPa versus Egauge = 180GPa) or other polymer materials typically utilized for composites.

By the strain gauge according to the invention comprising at least one reinforcement member placed at each end of the measurement grid in the axial direction is obtained a strain gauge where the strain field perturbations induced by the strain gauge on the material to be measured on are reduced considerably. These reinforcement members have been seen to advantageously provide for a significant reduction in the edge effect when placed sufficiently close to the measurement grid. The effect of the reinforcement members increase the closer the reinforcement members are placed to the measurement grid and is seen to be pronounced for a distance smaller than or equal to 5 times the grid spacing. In an embodiment the reinforcement members are each placed at a distance to the measurement grid in the range of 0.01-2.00 mm such as in the range of 0.05-1.0 mm such as in the range of 0.04-0.15 mm.

Numerical analyses on strain gauges according to the invention have shown that the positioning of the reinforcement members at both ends of the measurement grid and within the specified axial distance leads to considerably reduced strain field perturbations in both ends of the measuring grid in the installed strain gauge, which is sometimes also referred to local reinforcement effects or edge effects.

Furthermore, this advantage is obtained for test specimens of a wide range of material and of different material stiffness.

Hereby is obtained a strain gauge yielding more precise measurements and with considerably reduced measurement errors or in-accuracies to a high degree independently of the material properties of the specimen which is tested. More precisely, the strain gauge design according to the invention reduces the measurement dependency on the stiffness of the test specimen significantly. This further leads to a significantly increased precision of the strain gauge when used on non-isotropic materials such as composites in general as for example fiber reinforced materials. The more anisotropic the test specimen, the more advantageous is the use of the strain gauge according to the invention compared to conventional strain gauges. As an example a unidirectional glass fiber composite has an axial stiffness on 35-45GPa in the fiber direction but a stiffness in 45 degree of less than 10GPa. The strain gauge according to the invention is seen to provide considerably more reliable and accurate measurements in this stiffness range.

Furthermore, the strain gauge according to the invention yields considerably more accurate measurements especially for more compliant materials. The strain gauge according to the invention thereby is especially advantageous for use in relation to measurements on materials of lower stiffness in all or some directions such as for example on most plastic materials or fiber reinforced composites.

Further, as the improved strain gauge according to the invention is less stiffness dependent, is also obtained a more constant gauge factor or correction parameter during deformation. Hereby, the strain gauge according to the invention can be applied to obtain more accurate stress strain curves of test specimens of very different stiffness properties and also in the case of initially stiffer metallic materials. The reinforcement members of the strain gauge thus considerably reduce or eliminate an effect otherwise causing significant errors in material properties determination.

The reinforcement members close to the measurement grid according to the invention has furthermore been shown to result in strain gauges yielding far more accurate results as compared to a conventional strain gauge, when used to measure strain on components comprising a relatively thin outermost layer of a different material such as for example a coating layer. The improved strain measurements increase the thinner the superficial layer on the component. This means, that the strain gauge according to the invention are far more accurate when applied to e.g. composite components such as wind turbine blades or the like, as such components are both of a relatively compliant material, anisotropic, and often with an outermost thin protective layer such as a coating.

The carrier layer may comprise a film-type carrier layer, a substrate, or a foil, and may be formed in total or in part by a resin or a plastic material such as for example Polyamide.

The strain gauge may comprise further layers such as a backing layer, an adhesive layer, or a protective layer or coating on top of the measurement grid.

The measurement grid may be positioned or placed on the carrier layer by an adhesive or otherwise bonded to or deposited on the carrier layer. Likewise, the two reinforcement members can be positioned on the carrier layer by an adhesive or otherwise bonded to or deposited on the carrier layer. In an embodiment the measurement grid and or the reinforcement members are positioned on the carrier layer by etching techniques.

The measurement grid is meandering or arranged in a pattern such as to measure a deformation in an axial direction of the strain gauge as is commonly known from the manufacture of strain gauges. The measurement grid is formed from a number of grid sections extending primarily in the axial direction, placed side by side in an essentially parallel relationship or slightly zig-zagging, and connected in end loops at both ends of the measurement grid. The measurement grid may be formed from e.g. very thin wire or thin strips of metallic film deposited or otherwise positioned on the carrier layer. The wire width of conventional strain gauges may be in the range of 0.01 mm to 0.1 mm or even smaller. The grid sections are placed with gaps in between or a distance apart. The grid sections in the measurement grid may be placed uniformly in the entire or parts of the measurement grid. In an embodiment, all the grid sections in the measurement grid are placed with approximately the same spacing. In another embodiment the strain gauge comprises a central portion wherein the grid sections are placed with approximately the same spacing. The end loops may attain different lengths and shapes such as rounded or square. The measurement grid may further comprise struts placed near the ends.

The wire sections are conventionally placed as close as practically possible without touching in order to minimize the resistance changes of the measurement grid caused by other deformations than those in the axial direction which are to be detected and measured. The grid sections may be placed with a wire distance or gaps in between in the range of 0.01-1.00 millimeters such as in the range of 0.02-0.5 millimeters.

The advantageous effect of the reinforcement members as described in the previous has been demonstrated in numerical studies both when compared to strain gauges with no reinforcement members or with only one reinforcement member at one end of the strain gauge only. The improvement of the strain gauge performance is also significant and clearly demonstrated when compared to a strain gauge with conventionally placed soldering tabs as will be discussed in relation to figures 4-11.

As the reinforcement members are positioned within an axial distance of a factor times the gap distance, the factor being in the range of 1-5, is obtained that the reinforcement members are positioned at a distance which is practically possible to manufacture since it is comparable to the gap distance or grid spacing of the measurement grid. In this way the reinforcement members may advantageously be positioned e.g. by deposition on the carrier layer in the same manufacturing step as the positioning of the measurement grid. Numerical analyses have shown significantly reduced local effects and thereby increased efficiency of the strain gauges with reinforcement members placed at different distances within up to and including 3 times the grid distance. Further, an effect is believed to exist for the reinforcement members being placed within a distance up to 5 times the grid spacing. Analyses have further shown that the advantageous effects of the reinforcement members increase the closer the members are positioned to the measurement grid.

The at least two reinforcement members may advantageously be formed completely or in parts by the same material as the measurement grid, which may be advantageous during manufacturing.

The two reinforcement members may be placed at the same axial distance to the measurement grid or at different distances. The strain gauge may comprise more than two reinforcement members. The reinforcement members may have the same shape and/or size. Alternatively, one reinforcement member may be larger than another reinforcement member or may have a different shape.

In an embodiment of the invention, the axial distance is equal to or smaller than a wire factor times a width of a grid section, wherein the wire factor is in the range of 0.5-5, such as in the range of 1-2, such as approximately 1. Often the wire width (i.e. the width of the grid section) is comparable to the gap distance. The wire width of conventional strain gauges may be in the range of 0.01 mm to 0.1 mm or even smaller. As mentioned in the previous, the placing of an reinforcement member at each end of the strain gauge has proven advantageous when placed sufficient close to the measurement grid to act to significantly reduce the local effects of the strain gauge and thereby decrease the measurement error of the strain gauges most signicantly but not only for the more compliant material.

In an embodiment the reinforcement members extend a length in the axial direction of at least 0.5 mm. Hereby is obtained that the reinforcement members act to reinforce the strain gauge such as to considerably reduce the local effects arising from the stiffness mismatch and thereby reducing the stiffness dependency of the strain gauge correspondingly.

According to an embodiment of the invention, at least one of the reinforcement members extend a length in the axial direction of at least 0.5 mm plus a percentage of the length of the measurement grid in the axial direction, wherein the percentage is in the range of 5-50%, such as in the range of 10-30% such as of approximately 25%. It has been observed that the extension of the reinforcement members in the axial direction affects the measurement accuracy of the strain and that an increased efficiency of the strain gauge is obtained for longer reinforcement members. Furthermore, it has been observed that if a longer measurement grid is chosen for the strain gauge, then correspondingly longer reinforcement members are likewise more effective. A more precise strain gauge may thus be obtained when the lengths of the reinforcement members in the axial direction are chosen in dependency of the length of the measurement grid. The reinforcement members have been seen to advantageously have a length given as a function of the length of the measurement grid, where the function is an approximately linearly increasing function.

The desired reinforcing effect of the reinforcement members on the strain gauge may be obtained in different ways or by combinations hereof. For example by a certain axial extension of the reinforcement members as described above or by having one or more reinforcement members of increased thickness or of less compliant material at least as applied in the axial direction of the strain gauge.

Therefore, in one embodiment, the thickness of at least one of the reinforcement members is essentially the same as the thickness of the measurement grid. This may be advantageous from a manufacturing view point, as the reinforcement members may then advantageously be manufactured from a foil of the same type as the measurement grid or be applied by the same manufacturing processes. It may further be an advantage that the reinforcement members then do not increase the overall thickness of the strain gauge.

In another embodiment, the thickness of at least one of the reinforcement members is larger than the thickness of the measurement grid such as in the range of 1.5-5 times thicker. Hereby is obtained an increased reinforcing effect of the reinforcement members leading to the previously described effects of a strain gauge with reduced local effects and improved efficiency. Additionally, the same or comparable reinforcing effect can be obtained with a shorter but thicker reinforcement member. In this way the overall length of the strain gauge can be shortened by increasing the thickness of one or more of the reinforcement members while still obtaining the improved strain gauge design.

In another embodiment, the thickness of at least one of the reinforcement members is smaller than the thickness of the measurement grid and the length of the reinforcing member then correspondingly longer to thereby maintain the desired reinforcing effect.

In an embodiment, at least one of the reinforcement members and the measurement grid are made of the same material which may be advantageous from a manufacturing view point, as the reinforcement members may then advantageously be manufactured from a foil of the same type as the measurement grid or be applied by the same manufacturing processes. Alternatively, one or more of the reinforcement members are made of a material with a higher stiffness than the material of the measurement grid. Hereby the same advantageous reinforcing effect of the reinforcement members can be obtained with a shorter or a thinner reinforcement member or by combinations hereof.

The reinforcement members may in one embodiment of the invention have a width in a direction transverse to the axial direction of at least 80% of the width of the measurement grid such as approximately the same width. Hereby the reinforcement members are seen to advantageously affect the strain field across the majority or even more advantageously across the entire width of the measurement grid thereby reducing the undesired local effects effectively.

Alternatively, the reinforcement members may be wider in the direction transverse to the axial direction than the measurement grid. However, the portion of the reinforcement member extending beyond the width of the measurement grid is believed to add only little or not at all to the reinforcing effect of the reinforcement members.

In an embodiment of the invention, the strain gauge further comprises at least one soldering tab integrated with at least a portion of one of the reinforcement members. Hereby is obtained that the reinforcement member may both act to provide the desired reinforcing effect on the strain gauge and be used as a soldering tab for the strain gauge.

In an embodiment one of the reinforcement members is separated or divided into two or more portions, of which two portions each forms a part of a soldering tab. Hereby the soldering tabs may conveniently be placed at one end of the strain gauge and on the same time used to provide the advantageous reinforcing effect improving the efficiency of th strain gauge.

Alternatively, one reinforcement member at one end of the measurement grid may form part of one soldering tab, whereas another reinforcement member at the other end of the measurement grid forms part of the second soldering tab.

Alternatively, the reinforcement members are in one embodiment placed electrically separate from the measurement grid and thereby as such do not form part of the electrical circuit of the strain gauge.

In an embodiment of the invention one or more of the reinforcement members are patterned such as for example striped or comprising a number of longitudinal portions. The longitudinal portions may extend in the axial direction whereby the reinforcement member in one embodiment may advantageously be formed by a grid similar to the grid in the measurement grid. Hereby the reinforcement member may for example by made in an etching process or from a grid foil corresponding to the one used to the measurement grid. The longitudinal portions may alternatively or additionally extend at an angle to the axial direction.

In an embodiment of the invention, the width of a grid section, and/or the axial distance between each reinforcement member and the grid is in the range of 0.01-1.00 millimeters such as in the range of 0.02-0.5 millimeters.

In an embodiment of the invention, the measurement grid has a length in the range of 1.00 – 15.00 mm such as in the range of 1.25 - 10.00 mm , such as for example 1.50, 3.00, or 10.00 mm, and wherein the reinforcement members extend a length in the axial direction in the range of 0.5 - 5.0 mm, such as in the range of 1.0 - 4.5 mm, such as for example 1.5, 2.0, or 3.5 mm.

A large number of numerical analyses were performed primarily based on numerical models of six commercially available strain gauges sold by the manufacturer HBM under the names HBM Y series – S.G. Types 1-LY11-1.5/120, S.G. Types 1-LY11-3/120, and S.G. Types 1-LY11-10/120, and S.G. Types 1-LY11-1.5/350, S.G. Types 1-LY11-3/350, and S.G. Types 1-LY11-10/350 and based on the data of these strain gauges are as given by the manufacturer in the table in figure 27 and as measured with reference to the table in figure 28.

Based on these data, numerical tests were performed with different sizes of reinforcement member for the different sizes of the measurement grids of the strain gauges. Based on these analyses, the above mentioned dimensions for the axial distance and reinforcement member length were found to be especially advantageous.According to a further aspect, the invention relates to a multi-axial strain gauge comprising two or more strain gauges according to any of the above, and where the strain gauges are oriented differently. Hereby, each of the strain gauges in the multi-axial strain gauge obtain the advantages as described in the previous resulting in multi-axial strain gauge with correspondingly improved efficiency and measurement accuracy.

The multi-axial strain gauge may be a bi-axial strain gauge comprising two strain gauges placed orthogonally or may be a strain gauge rosette of three strain gauges placed at different angles such as in 0/60/120° or 0/45/90°.

In an embodiment wherein one or more of the strain gauges in the multi-axial strain gauge forms part of the reinforcement member of another of the strain gauges. Hereby is obtained a multi-axial strain gauge with the desired improved measurement characteristics with fewer elements in the design and of smaller size and more compact. Further a reduced amount of material is needed.

The invention further relates to a method of manufacturing a strain gauge according to any of the above comprising the steps of forming a meandering measurement grid of a number of interconnected grid sections placed side by side with gaps in between, positioning the measurement grid on a carrier layer, positioning two reinforcement members on the carrier layer at opposite ends of the measurement grid and establishing an axial distance between the measurement grid and each reinforcement member, the axial distance not exceeding a factor times the gap distance, wherein the factor is in the range of 1-5, such as in the range of 1-3, such as approximately 3.

The advantages hereof are further as described in the above in relation to the strain gauges according to the invention. Further, the strain gauge may hereby be manufactured simple and fast using conventional manufacturing techniques from strain gauge manufacturing.

Brief description of the drawings

In the following different embodiments of the invention will be described with reference to the drawings, wherein:

Figs. 1A-C show prior art strain gauges of three different lengths and used for comparison to embodiments of strain gauges according to the invention,

Fig. 2 shows the measurement error of the prior art strain gauges of figs 1A-C as function of test specimen stiffness,

Fig. 3 shows an embodiment of a strain gauge according to the invention comprising two reinforcement members,

Fig. 4 shows the measurement error of the strain gauge of figure 3 for different lengths of the reinforcement members and compared to the reference prior art strain gauge of figure 1A,

Fig. 5 shows an embodiment of a longer strain gauge according to the invention comprising two reinforcement members,

Fig. 6 shows the measurement error of the strain gauge of figure 5 for different lengths of the reinforcement members and compared to the reference prior art strain gauge of figure 1B,

Fig. 7 shows an embodiment of an even longer strain gauge according to the invention comprising two reinforcement members,

Fig. 8 shows the measurement error of the strain gauge of figure 7 for different lengths of the reinforcement members and compared to the reference prior art strain gauge of figure 1C,

Figs. 9A-C show embodiments of strain gauges according the invention of three different lengths,

Figs. 10A-C show the measurement error of the strain gauges of figures 9A-C and compared to the reference prior art strain gauges of figure 1A-C,

Fig. 11 shows the optimal reinforcement member length as a function of the length of the measurement grid and for reinforcement members of the same and two times the thickness of the measurement grid,

Fig. 12 shows a strain gauge with a reinforcement member on only one side of the measurement grid,

Fig. 13 shows the measurement error of the strain gauge of figure 12 for different lengths of the single reinforcement member and compared to the reference prior art strain gauge of figure 1B and to an embodiment of a strain gauge according to the invention with two reinforcement members,

Fig. 14 shows an embodiment of a strain gauge according to the invention with patterned reinforcement members,

Fig. 15 shows the measurement error of the strain gauge of figure 14 for different lengths of the patterned reinforcement members and compared to the reference prior art strain gauge of figure 1B,

Fig. 16 shows the measurement error of embodiments of a strain gauge according to the invention corresponding to figure 5 for different distances between the measurement grid and the reinforcement members and compared to the reference prior art strain gauge of figure 1B,

Fig. 17 shows a prior art bi-axial strain gauge,

Figs. 18A-B show two embodiments of a bi-axial strain gauge according to the invention comprising reinforcement members,

Fig. 19 shows the measurement error of the bi-axial strain gauges of figures 18A-B and compared to the prior art strain gauge of figure 17,

Fig. 20 shows a prior art bi-axial 0/90° strain gauge,

Figs. 21-22 show two embodiments of a bi-axial 0/90° strain gauge according to the invention comprising reinforcement members, and

Fig. 23 shows an embodiment of a multi-axial strain gauge rosette according to the invention comprising reinforcement members,

Figs. 24 and 25 show two embodiments of a strain gauge according to the invention with alternative soldering tabs,

Figs. 26A-B illustrate strain gauge for indication of different strain gauge parameters, and

Figs. 27 and 28 show tables of the parameters of commercially available strain gauges HBM Y series – S.G. Types 1-LY11-1.5/350, 1-LY11-3/350, and 1-LY11-10/350 used as reference strain gauges for comparison to embodiments of strain gauges according to the invention.

Detailed description of the drawings

Figures 1A-C and 26A and 26B show some typical strain gauges 100 as known from prior art and for measuring deformations in the axial directions 103 of the strain gauges. Figure 26A shows a commercial available strain gauge as available from the company HBM and sold in different types with the parameters as given in figure 27. In figure 26B is further shown a schematic drawing of a strain gauge 100 indicating the different parts and characteristic parameters of a strain gauge. The strain gauges comprise a measurement grid 101 of a grid length 102 (called *a* in figures 26A and 27) and overall width *b,* placed on a carrier layer or foil (as indicated in figure 26A and with the dimensions *c* and *d*). The measurement grid 101 is meandering and comprises a number of interconnected grid sections 104 of a width w and placed side by side with gaps w_g, 105 in between. The gap distance, wg, and the width of the grid sections or wire, *w* are indicated in figure 26B. The grid sections are connected in end loops 106 of a length, *l,* in the axial direction 103. The strain gauges all comprise solder tabs 107 which in these examples are both placed on one end of the strain gauge.

The strain gauges of figures 1A, B, and C differ mainly by the length of the measurement grid of 1.5 mm, 30 mm, and 10 mm, respectively, chosen as most common strain gauges have a grid length in the range from 1.5 mm to 10 mm.

A large number of numerical analyses were performed primarily based on numerical models of the three commercially available strain gauges sold by the manufacturer HBM under the names HBM Y series – S.G. Types 1-LY11-1.5/350 and S.G. Types 1-LY11-3/350, and S.G. Types 1-LY11-10/350, and variations hereof. The data of these strain gauges are as given by the manufacturer in the table in figure 27 and with reference to the schematic drawing in figure 26A. Additionally, the grid spacing or gap distance, *wg,* the width of the grid sections or wire width, *w,* and the end loop length, *l*, of these three strain gauges were measured. The measured values are given in the table in figure 28.In the numerical analyses, the strain gauges are made of Constantan (isotropic with a Elasticity module E=180 GPa and Poisson ration of 0.3), and the carrier layer has material properties corresponding to a Polyamide polymer (isotropic with a Elasticity module E=3.1 GPa and Poisson ration of 0.41) and with a thickness of 0.045 mm. The thickness of the measurement grid is 15 mm and the grid spacing or gap length between adjacent grid sections in the measurement grid is 0.03 mm, 0.04 mm, and 0.1 mm, for the three different strain gauges, respectively.

These parameters of the strain gauges of figures 1A-C have been chosen to match commercially available stain gauges closely sold under the names of HBM Y series – S.G. Types 1-LY11-1.5/350 and S.G. Types 1-LY11-3/350, and S.G. Types 1-LY11-10/350, respectively

The prior art strain gauges of figures 1A, B, and C are used in comparisons to embodiments of strain gauges according to the invention, and are as such referred to as reference strain gauges in the following, The performance of the prior art strain gauges of figures 1A, B, and C of different measurement grid lengths L_{grid} has been investigated and figure 2 shows the measurement error 200 of the strain gauges as a function of test specimen's Young Modulus (elasticity coefficients) $E_{material}$, 201 ranging from 1 GPa to 200 GPa. As can be seen from the graphs, all three strain gauges show very significant measurement errors especially for the lower stiffness coefficients. The more compliant the test specimen is, the more the measurement error increases.

Numerical analyses were also performed on the strain gauges of figures 1A-C but with the solder tabs 107 removed. These strain gauges showed even larger measurement errors for all test specimen elasticity.

Figure 3 shows an embodiment of a strain gauge 100 according to the invention. The strain has the same material properties and measurement grid dimensions as the strain gauge of figure 1A. The strain gauge according to the invention of figure 3 comprises two reinforcement members 301 which are placed at each opposite end of the measurement grid 101 in the axial direction 103 of the strain gauge. The reinforcement members are placed a distance d, 301 from the end of the measurement grid 101. In this embodiment, the distance d is approximately the same as the grid spacing, but could in other embodiments be larger. The reinforcement members extend a length L_{reinf}, 302 in the axial direction.

Parameter studies have been conducted of the performance of the strain gauge with different length 302 of the reinforcement members. Figure 4 shows the measurement error 200 of the strain gauge of figure 3 as a function of test specimen elasticity $E_{material}$ 201 and for different lengths of the reinforcement members L_{reinf} 302 of 0.5mm, 0.75mm, 1.0mm, and 1.5mm, respectively. For comparison is also plotted the measurement error of the prior art strain gauge without reinforcement members at both ends of figure 1A. As can be seen from the curves, the strain gauges according to the invention with a reinforcement member at each end of the measurement grid show considerably lower measurement errors especially for the more compliant test specimen materials. In this way the reinforcement members act to considerably reduce or remove the local effects from the stiffness mismatch between the strain gauge and the test specimen. The obtained strain gauges hereby may be used to obtain far more accurate strain or deformation measurements and with no or a reduced dependency of the stiffness or non-linearity of the tested material.

The numerical results showed that a small negative measurement error 200 occurred for the reinforcement member length 302 increased above a certain limit. The optimal length 302 in this case was determined to be of approximately 1.00 – 1,50 mm corresponding to the curve 400 marked with squares. Figure 9A shows an embodiment of such strain gauge according to the invention. In this embodiment the soldering tabs 107 of the strain gauge are formed by one of the reinforcement members 900. The reinforcement member 900 is separated into two portions each portion forming a part of a soldering tab. The other opposite reinforcement member 902 is electrically separate from the measurement grid 101. In an embodiment, one reinforcement member forms one soldering tab and the other opposite reinforcement member could form another soldering tab.

Figures 5 and 7 show embodiments of strain gauges according to the invention and comprising two reinforcement members 300 placed a distance d, 301 from the measurement grid. The strain gauges here have a measurement grid length L_{grid}, 102 of 3mm and 10mm, respectively, and are comparable to the prior art strain gauges of figures 1B and 1C, respectively.

Figures 6 and 7 show the measurement error of the strain gauges of figure 5 and 7, respectively. The dotted curves show the measurement error 200 for different lengths of the reinforcement members L_{reinf} ,302 and as a function of the stiffness $E_{material}$, 201 of the test specimen. The corresponding result for the reference prior art strain gauge of figures 1B and 1C are also shown in the figures for comparison.

For the strain gauge of the intermediate size with a measurement grid length, 102 of 3mm (figure 5) the optimal reinforcement length 302 was determined to be in the range of 1.25 to 2.00 mm, such as approximately 1.50 mm. A strain gauge with such parameters is shown in figure 9B.

For the strain gauge of the larger size with a measurement grid length, 102 of 10mm (figure 7) the optimal reinforcement length 302 was determined to be of around 3.5 mm. A strain gauge with such parameters is shown in figure 9C.

Figures 10A, B, and C show the measurement error, 200 of the optimized strain gauges of figures 9A-C as a function of test specimen stiffness, $E_{material}$, 201. Also shown in the figures is the measurement error of the reference prior art strain gauges of figure 1A-C. The measurement error on the optimized strain gauges is seen to be reduced within the +/- 1 % (as shown with small dots in the figures) on a wide range of specimen's stiffness values from 3 to 200 GPa.

In figure 11 is shown the optimized reinforcement member length L_{reinf}, 302 as a function of the length of the measurement grid L_{grid}, 102. The analyses were performed both with the thickness of the reinforcement members t_{reinf} being equal to and being the double the thickness of the measurement grid t_{grid}. In both cases, the optimized reinforcement member length increases with the length of the measurement grid of the strain gauge. In other words, more stiff reinforcement members are advantageous to reduce the local effect with longer measurement grids of the strain gauge. As can be seen from the figure, the effect of the reinforcement members can be improved by increasing the thickness of the reinforcement member, or a comparable effect can be obtained by a shorter but thicker reinforcement member.

In order to obtain the desired effect of reduced or removed local effect, the strain gauge is equipped with a reinforcement member at both ends of the measurement grid as described in the above. The same advantageous effects are not obtained with a reinforcement member on only one side of the measurement grid as for the strain gauge shown in figure 12.

The curves in figure 13 show the measurement error of the strain gauge of figure 12 for two different lengths, 302 of the single reinforcement member 1200 (curves 1301) and compared to the reference prior art strain gauge of figure 1B (curve 1303) and to an embodiment of a strain gauge according to the invention with two reinforcement members (curve 1302). As can be seen from the figure, although an improved result is obtained with the single reinforcement member, a far better result is obtained with a strain gauge with reinforcement members at both ends and even for relatively short lengths of the reinforcement members L_{reinf}. The improvement relative to the reference strain gauge, 1303, is believed to be obtained by the placing of the reinforcement members within a relatively short distance to the measurement grid.

Figure 14 shows an embodiment of a strain gauge according to the invention where the reinforcement members are patterned 1400. Here the reinforcement members comprise a number of longitudinal portions 1401 extending in the axial direction of the strain gauged. The reinforcement members may be formed in the same way as the measurement grid. The reinforcement members are here both placed at a distance to the measurement grid corresponding approximately to the grid spacing.

Figure 15 shows the measurement error of the strain gauge of figure 14 for different lengths L_{reinf} of the patterned reinforcement members and compared to the reference prior art strain gauge of figure 1B. The results show a significant effect of all the patterned reinforcement members, where the measurement error reduced with increasing length of the reinforcement members.

Figure 16 shows the measurement error of embodiments of a strain gauge according to the invention corresponding to figure 5 and for different distances *d,* 301 between the measurement grid 101 and the reinforcement members 300. For comparison is also shown the measurement error of the reference strain gauge of figure 1B. The three dotted curves are for a distance *d,* 301, between the reinforcement members and the measurement grid corresponding to 1, 2, and 3 times the grid spacing (i.e. gap size between adjacent grid sections in the measurement grid), respectively. The results show that an improved effect of the reinforcement members is obtained for all three distances, and an increased effect the closer the members are placed to the measurement grid.

In strain gauges according to the invention may furthermore advantageously be applied in multi-axial strain gauges. Figure 17 shows a prior art bi-axial strain gauge 1700 of two wired sections oriented at +/- 45 degrees. The parameters of this strain gauge match a commercially available stain gauge closely sold under the names of HBM – S.G. 1-XY21-1.5/350

Figures 18A and B show two embodiments of a bi-axial strain gauge 1800 according to the invention comprising reinforcement members. In figure 18A, the bi-axial strain gauge is composed of two sub strain gauges 1801 oriented in +/- 45 degrees. Here, each of the sub strain gauges comprises a reinforcement member at each opposite ends in the length direction (+/- 45 degrees) of each measurement grid 101. One of the reinforcement members 1802 acts as a reinforcement member to both of the sub strain gauges.

In the embodiment of figure 18B, the one measurement grid 101 acts as a reinforcement member 300 to the other sub strain gauge and vice versa. Hereby the centrally placed reinforcement member 1802 of the bi-axial strain gauge of figure 18A is not a requirement to obtain the more efficient bi-axial strain gauge.

The measurement error of the bi-axial strain gauges of figures 18A-B and compared to the prior art strain gauge of figure 17 is shown in figure 19. The results are given for two different lengths of the reinforcement members L_{reinf}. A considerably reduced measurement error can be seen for all values of test specimen elasticity, 201.

Figure 20 shows a prior art bi-axial strain gauge 2000 of two wired sections oriented at 0/90 degrees. The parameters of the strain gauges have been chosen to match the commercially available stain gauge sold under the name of HBM – S.G. Types 1-XY11-3/350.

Figures 21 and 22 show two embodiments of a bi-axial strain gauge 2100 according to the invention and where the strain gauges comprise reinforcement members. Here, the bi-axial strain gauge comprises two sub strain gauges 1801 oriented in 0/90 degrees. Each of the sub strain gauges comprises a reinforcement member 300 at each opposite end of the measurement grids 101 in the length direction (0/90 degrees).

Figure 23 shows an embodiment of a multi-axial strain gauge rosette 2300 according to the invention comprising three sub strain gauges 100 and oriented in different axial directions 103. Each sub strain gauge of the rosette 2300 comprises two reinforcement members 300 placed at opposite ends of the measurement grid 101. Like for the bi-axial strain gauges described above, in some embodiments, one or both reinforcement members of a sub strain gauge may be formed by a part of one of the other sub strain gauges.

Figure 24 and 25 two embodiments of a strain gauge according to the invention with alternative solutions for the forming of the soldering tabs 107. In figure 24, the soldering tabs are placed at least partly next to and on either side of one of the reinforcement members 300. In figure 25 the reinforcement members are patterned each comprising a number of longitudinal portions extending in the axial direction of the strain gauge. Further, the soldering tabs act at least partly as the reinforcement member in the one end. In both designs of figure 24 and 25, the soldering tabs have been placed such as to not increase the overall length of the strain gauge.

While preferred embodiments of the invention have been described, it should be understood that the invention is not so limited and modifications may be made without departing from the invention. The scope of the invention is defined by the appended claims, and all devices that come within the meaning of the claims, either literally or by equivalence, are intended to be embraced therein.

CLAIMS

1. A strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the measurement grid is arranged such as to measure a deformation in an axial direction of the strain gauge and comprises a number of interconnected grid sections placed side by side with gaps in between, the strain gauge further comprising two reinforcement members positioned on the carrier layer at opposite ends of the measurement grid in the axial direction,
where the reinforcement members are each placed with an axial distance to the grid with the axial distance being equal to or smaller than a factor times the gap distance, wherein the factor is in the range of 1-5, such as approximately 1.

2. A strain gauge according to claim 1, wherein the axial distance is equal to or smaller than a wire factor times a width of a grid section, wherein the wire factor is in the range of 0.5-5, such as in the range of 1-2, such as approximately 1.

3. A strain gauge according to claim 1 or 2, wherein the reinforcement members extend a length in the axial direction of at least 0.5 mm.

4. A strain gauge according to any of the preceding claims wherein the thickness of at least one of the reinforcement members is essentially the same as the thickness of the measurement grid.

5. A strain gauge according to any of claims 1-3, wherein the thickness of at least one of the reinforcement members is larger than the thickness of the measurement grid such as in the range of 1.0-5 times thicker.

6. A strain gauge according to any of the preceding claims wherein at least one of the reinforcement members and the measurement grid are made of the same material.

7. A strain gauge according to any of the preceding claims wherein at least one of the reinforcement members extend a length in the axial direction of at least 0.5 mm plus a percentage of the length of the measurement grid in the axial direction, wherein the percentage is in the range of 5-50%, such as in the range of 10-30% such as of approximately 25%.

8. A strain gauge according to any of the preceding claims wherein the reinforcement members have a width in a direction transverse to the axial direction of at least 80% of the width of the measurement grid.

9. A strain gauge according to any of the preceding claims wherein the reinforcement members are of approximately the same width as the measurement grid.

10. A strain gauge according to any of the preceding claims further comprising at least one soldering tab integrated with at least a portion of one of the reinforcement members.

11. A strain gauge according to claim 10 wherein one of the reinforcement members is separated into two portions, each portion forming a part of a soldering tab.

12. A strain gauge according to any of claims 1-9, wherein the reinforcement members are electrically separate from the measurement grid.

13. A strain gauge according to any of the preceding claims wherein the reinforcement members are patterned.

14. A strain gauge according to claim 13 wherein the reinforcement members comprises a number of longitudinal portions extending in the axial direction or at an angle to the axial direction.

15. A strain gauge according to any of the preceding claims wherein the width of a grid section, and/or the axial distance between each reinforcement member and the grid is in the range of 0.01-1.00 millimeters such as in the range of 0.02-0.5 millimeters.

16. A strain gauge according to any of the preceding claims wherein the measurement grid has a length in the range of 1.00 – 15.00 mm such as in the range of 1.25 - 10.00 mm , such as for example 1.50, 3.00, or 10.00 mm, and wherein the reinforcement members extend a length in the axial direction in the range of 0.5 - 5.0 mm, such as in the range of 1.0 - 4.5 mm, such as for example 1.5, 2.0, or 3.5 mm.

17. A multi-axial strain gauge comprising two or more strain gauges according to any of claims 1-16 oriented differently.

18. A multi-axial strain gauge according to claim 17 wherein one of the strain gauges forms part of the reinforcement member of another of the strain gauges.

19. A multi-axial strain gauge according to any of claim 17-18 comprising a bi-axial strain gauge or a strain gauge rosette.

20. A method of manufacturing a strain gauge according to any of claims 1-16 comprising the steps of forming a meandering measurement grid of a number of interconnected grid sections placed side by side with gaps in between, positioning the measurement grid on a carrier layer, positioning two reinforcement members on the carrier layer at opposite ends of the measurement grid and establishing an axial distance between the measurement grid and each reinforcement member, the axial distance not exceeding a factor times the gap distance, wherein the factor is in the range of 1-5, such as approximately 1.

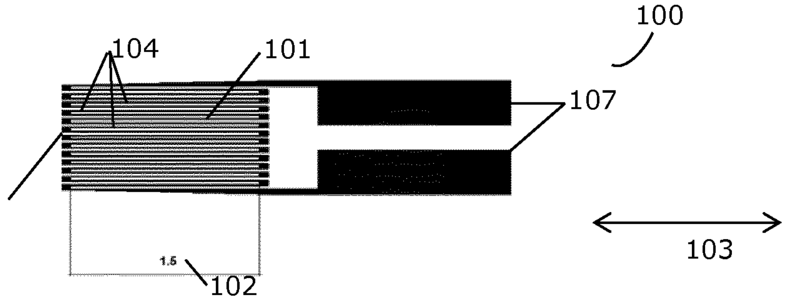


Fig. 1A
(prior art)

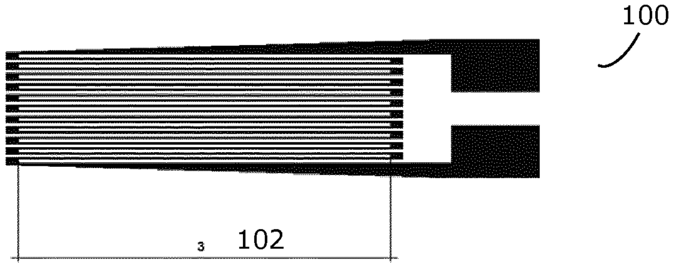


Fig. 1B
(prior art)

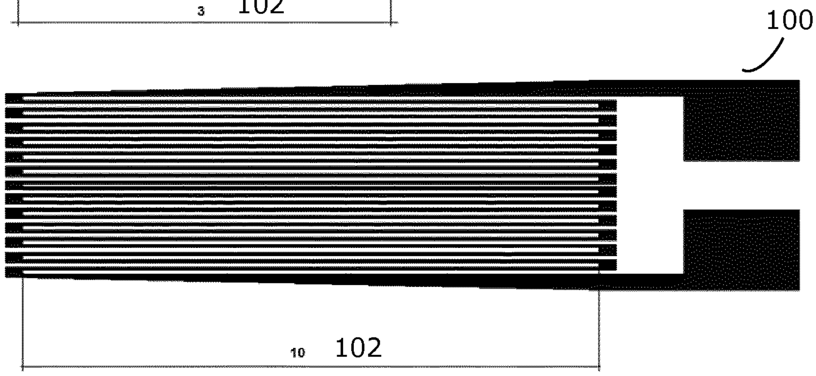


Fig. 1C
(prior art)

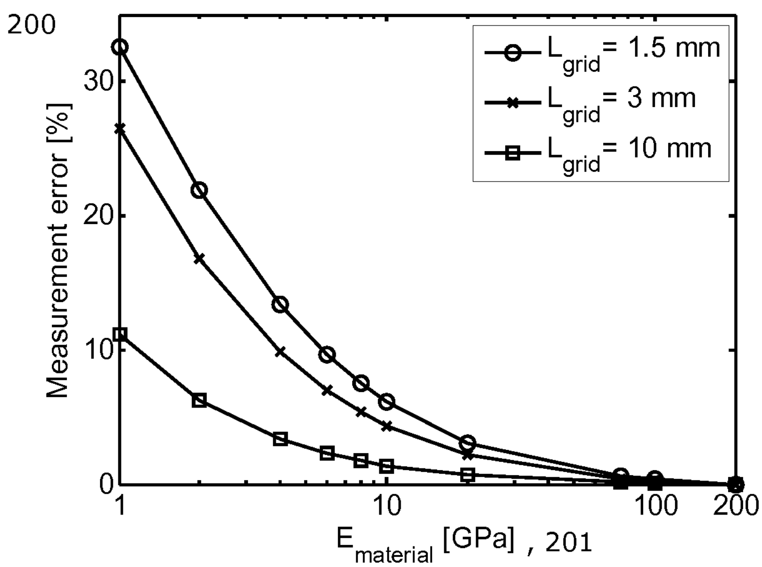


Fig. 2

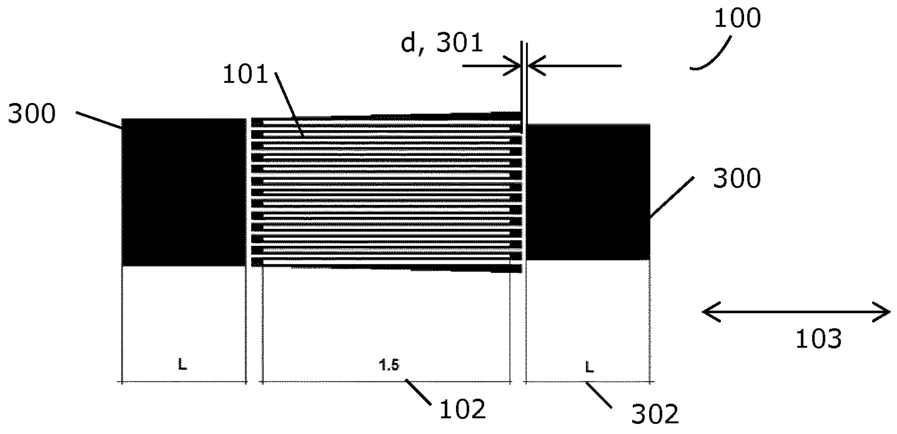

100
d, 301
101
300
300
L
1.5
L
103
102
302

Fig. 3

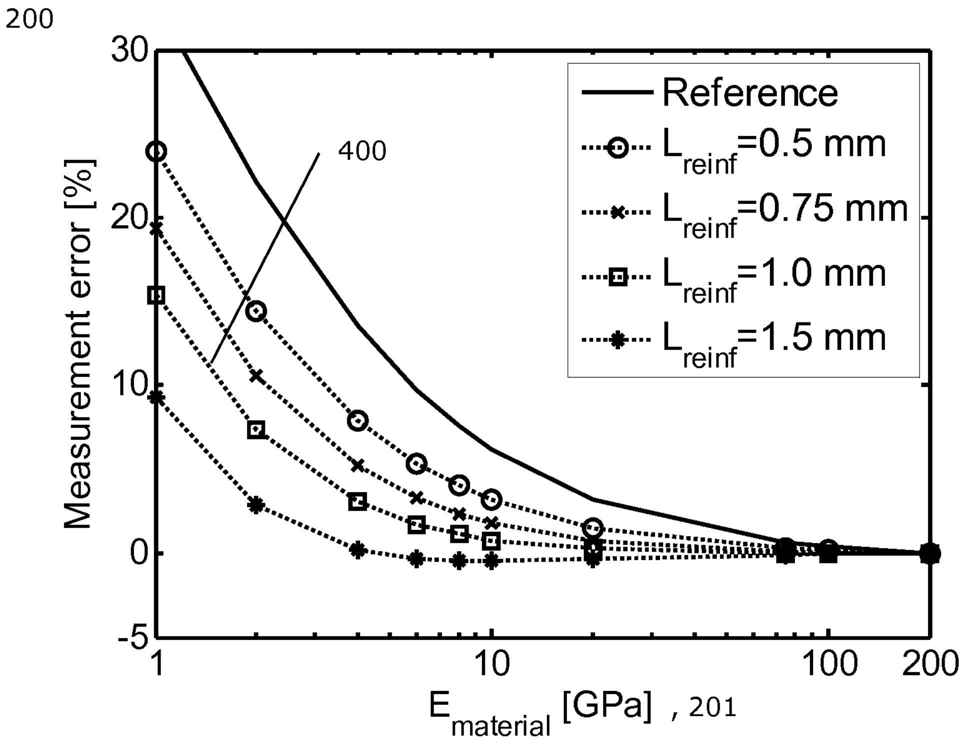

200
400
Reference
Lreinf=0.5 mm
Lreinf=0.75 mm
Lreinf=1.0 mm
Lreinf=1.5 mm
Measurement error [%]
30
20
10
0
-5
1
10
100
200
Ematerial [GPa] , 201

Fig. 4

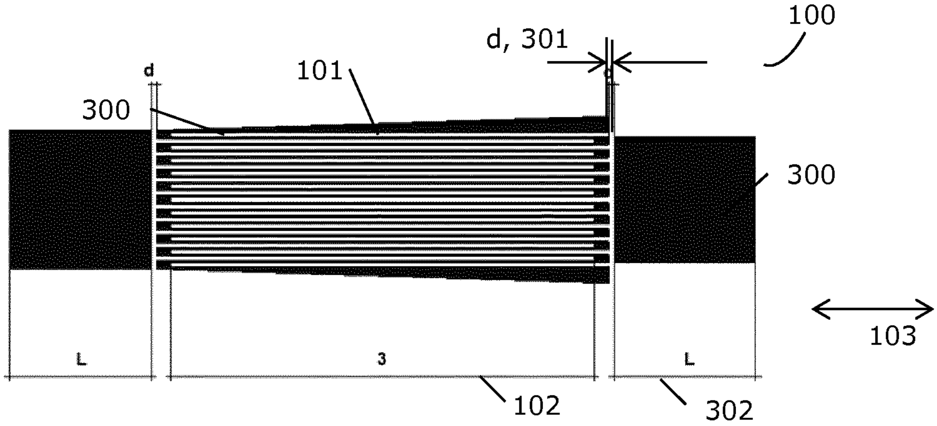

100
d, 301
d
101
300
300
103
L
3
L
102
302

Fig. 5

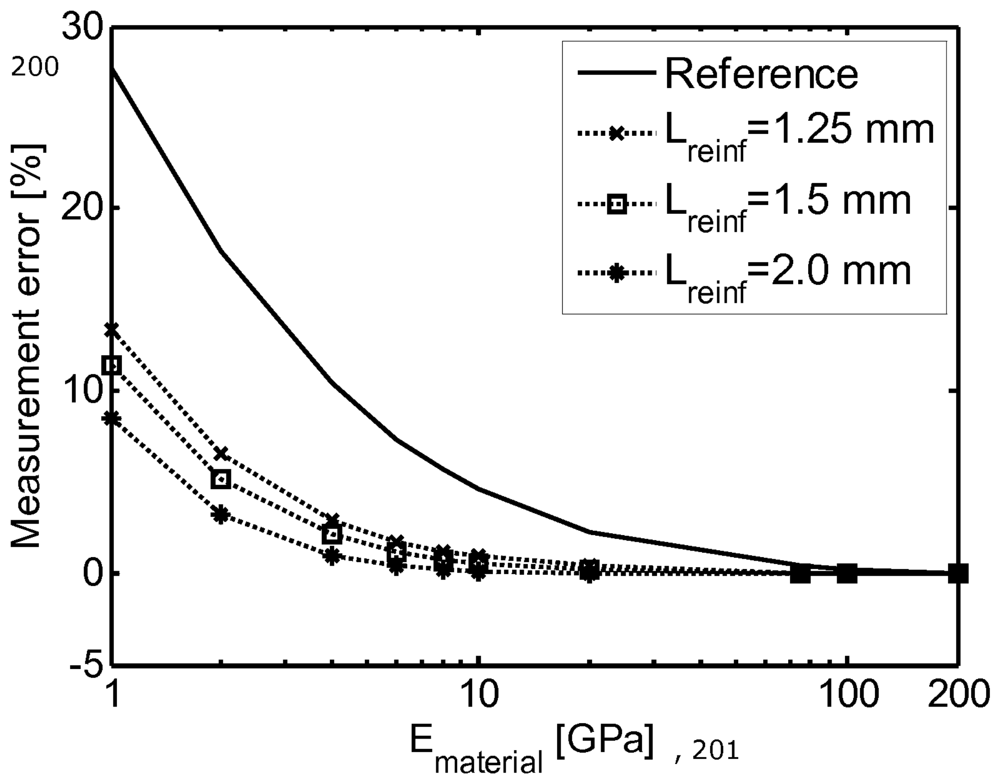

30
200
20
10
0
-5
Measurement error [%]
Reference
L_{reinf}=1.25 mm
L_{reinf}=1.5 mm
L_{reinf}=2.0 mm
1
10
100
200
$E_{material}$ [GPa] , 201

Fig. 6

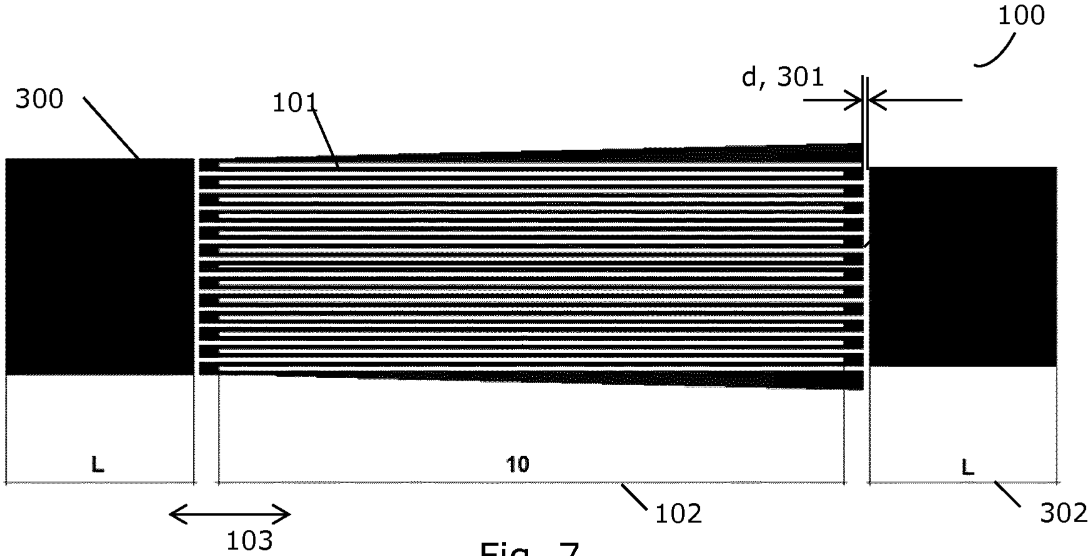

100
d, 301
300
101
L
10
L
103
102
302

Fig. 7

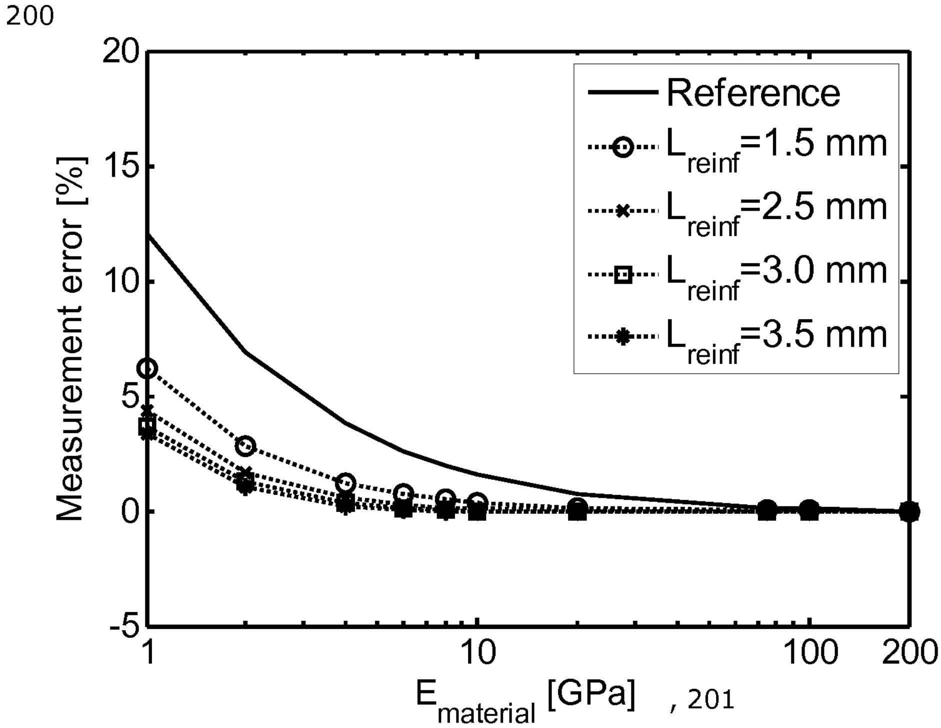

200
Reference
Lreinf=1.5 mm
Lreinf=2.5 mm
Lreinf=3.0 mm
Lreinf=3.5 mm
Measurement error [%]
20
15
10
5
0
-5
1
10
100
200
Ematerial [GPa]
, 201

Fig. 8

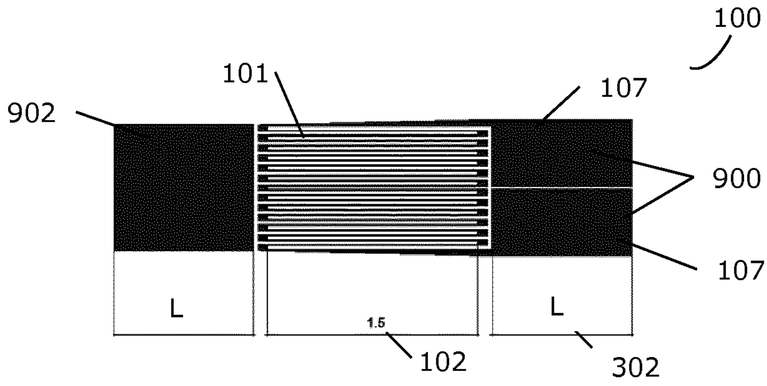


Fig. 9A

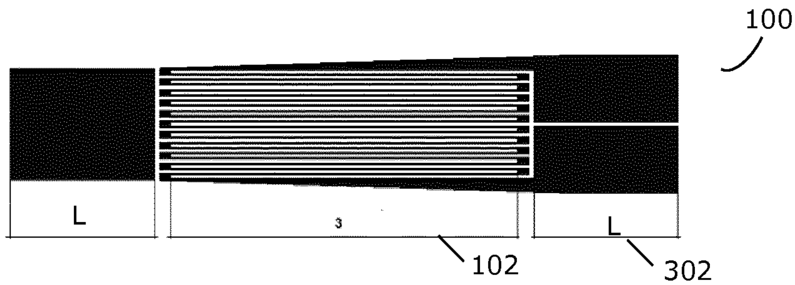


Fig. 9B

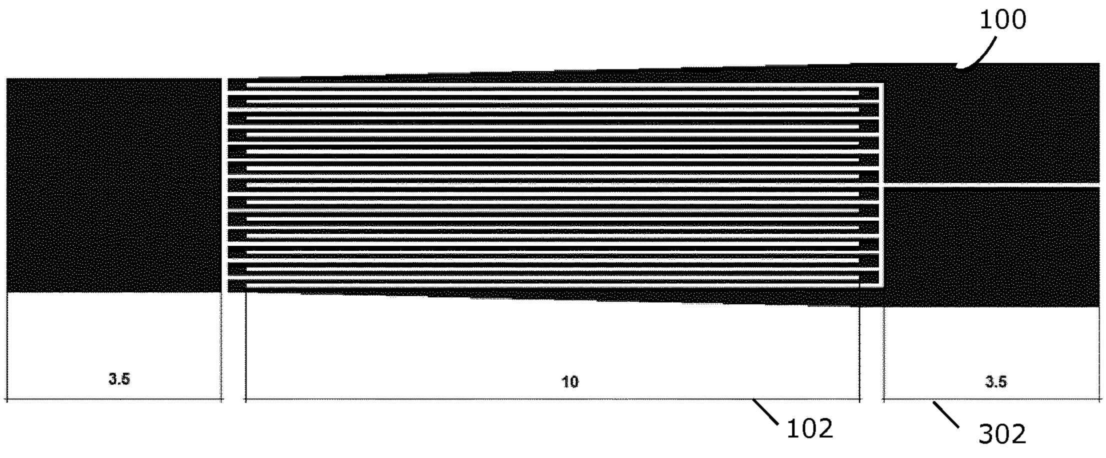


Fig. 9C

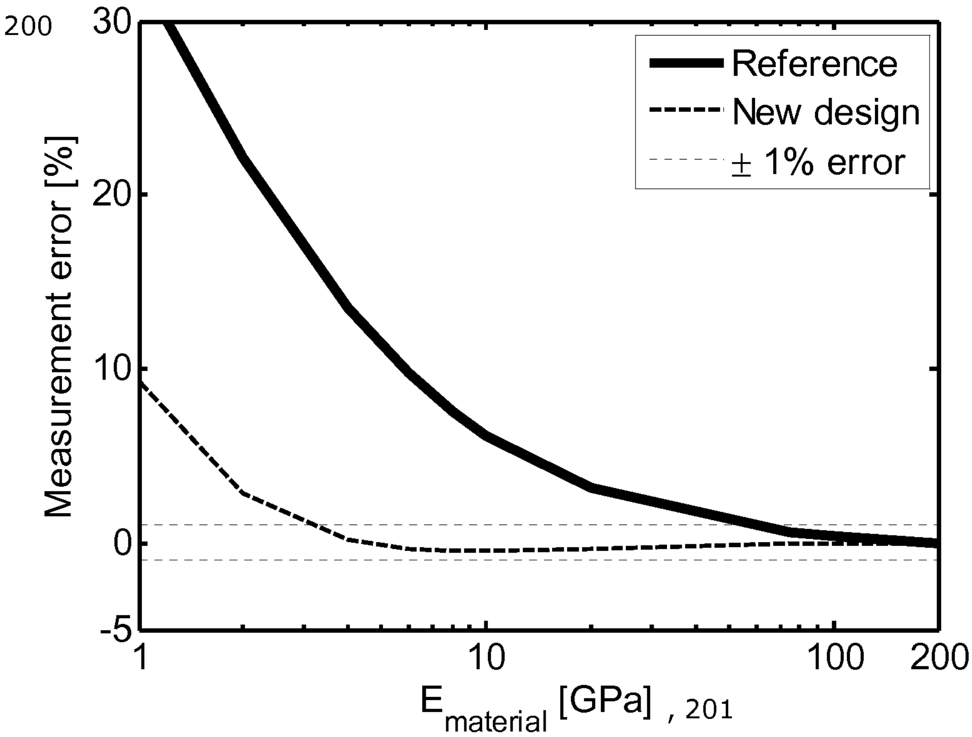


Fig. 10A

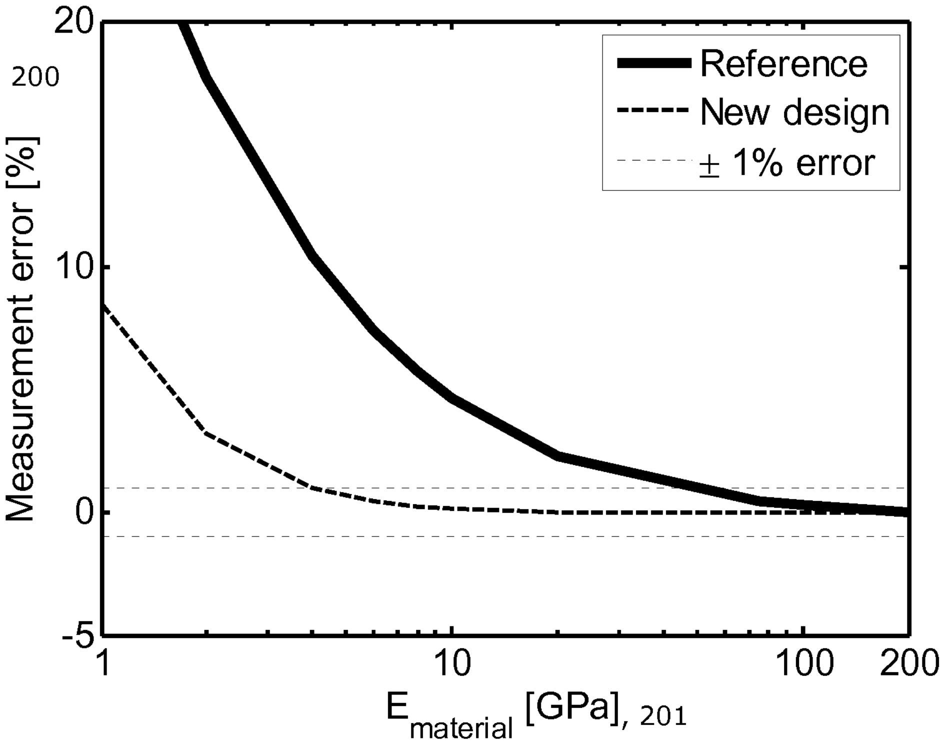


Fig. 10B

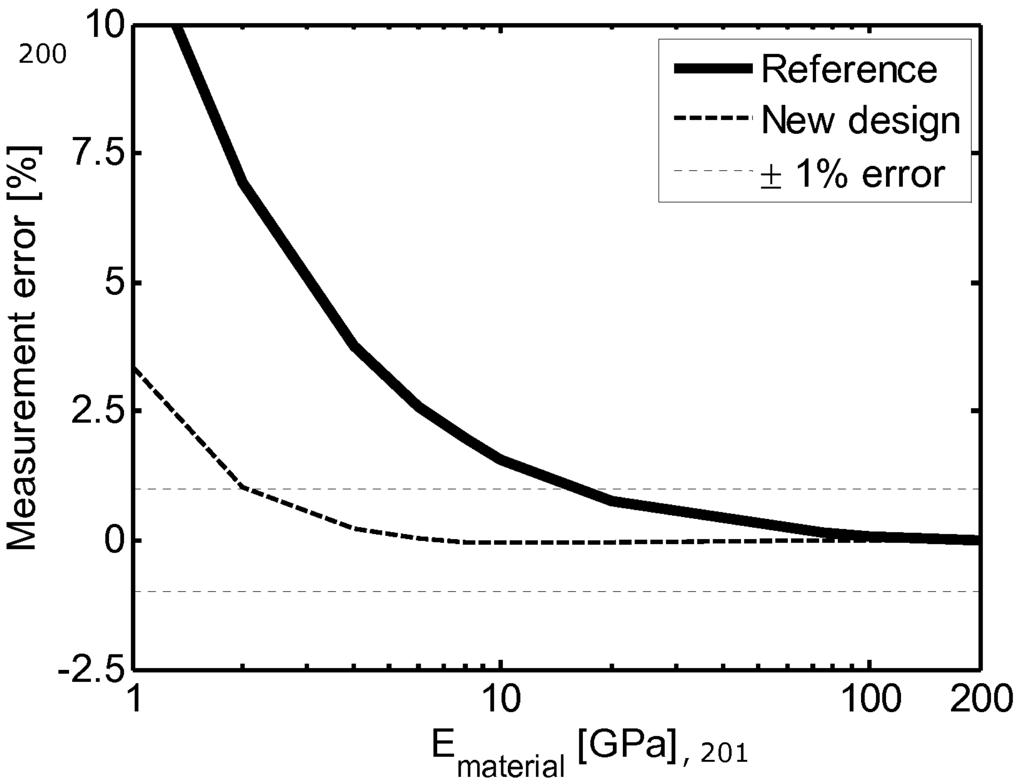


Fig. 10C

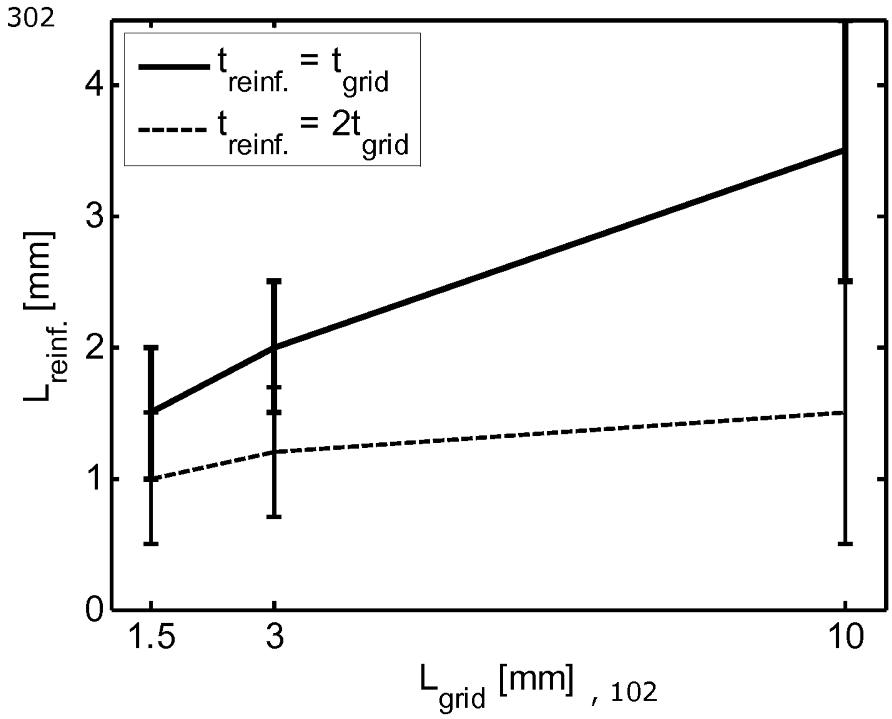


Fig. 11

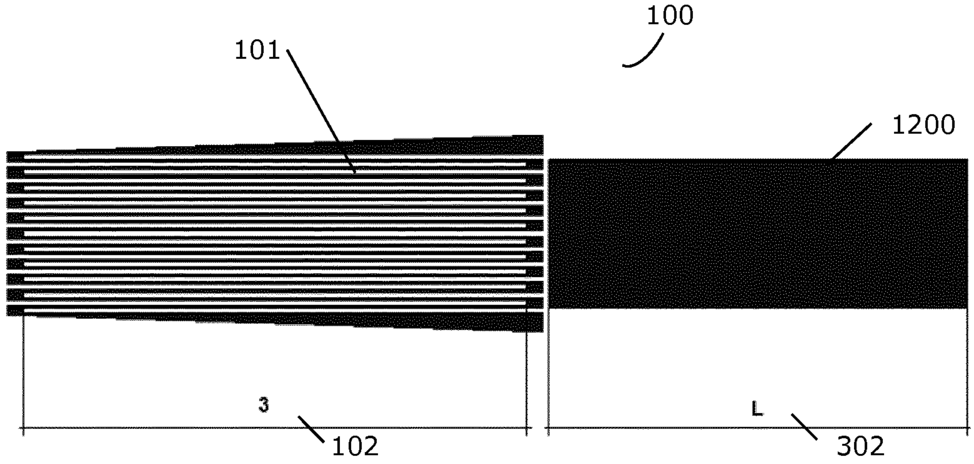

100
101
1200
3
L
102
302

Fig. 12

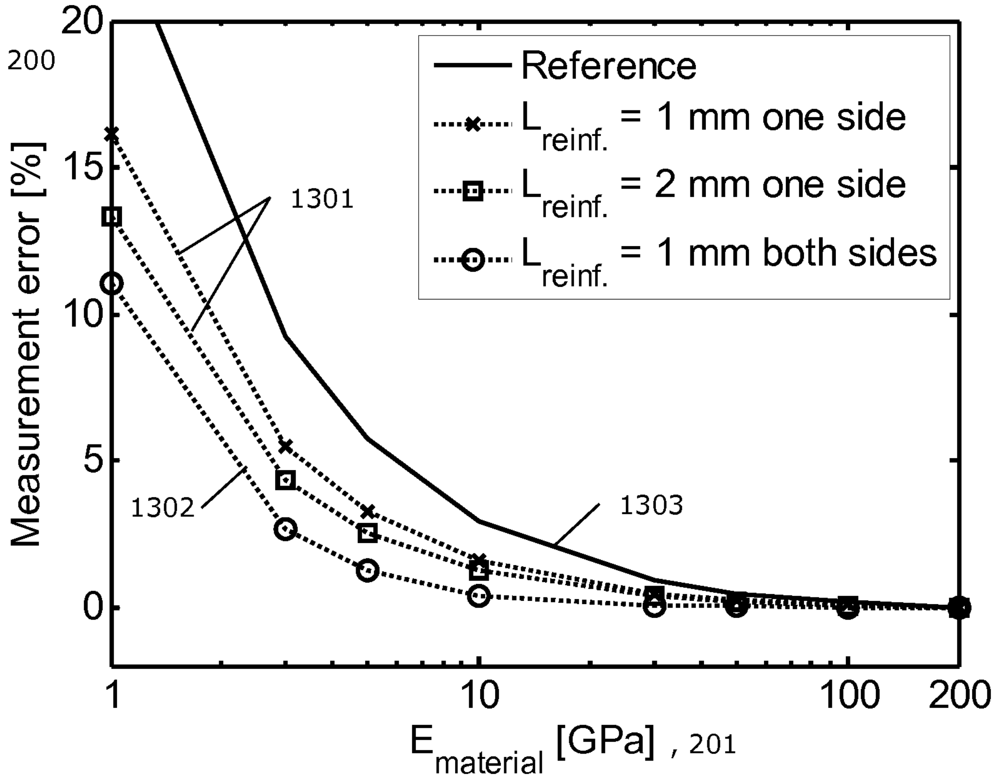

200
Measurement error [%]
20
15
10
5
0
1301
1302
1303
Reference
L reinf. = 1 mm one side
L reinf. = 2 mm one side
L reinf. = 1 mm both sides
1
10
100
200
E material [GPa] , 201

Fig. 13

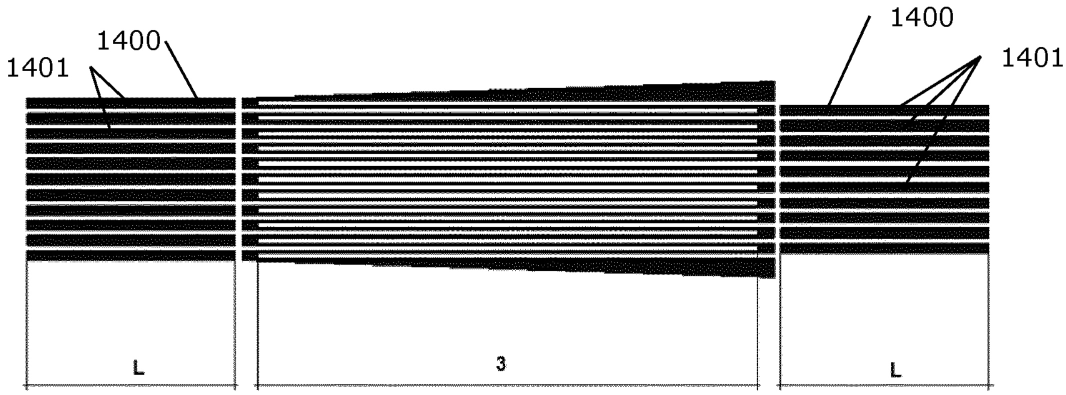

1401
1400
1400
1401
L
3
L

Fig. 14

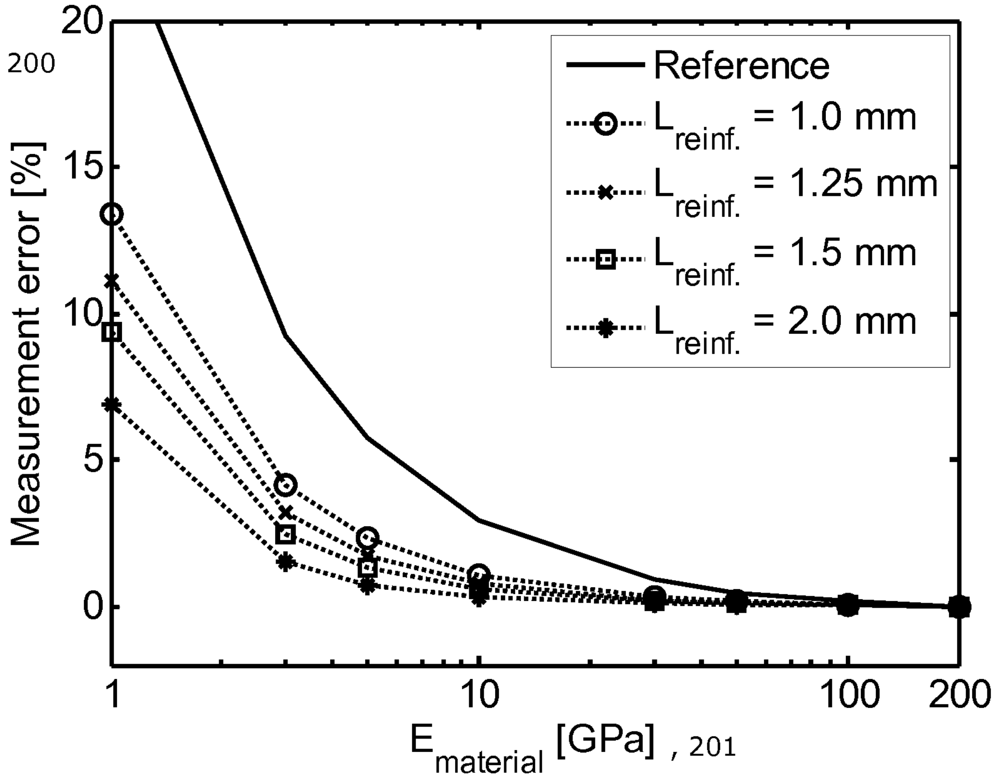

Reference
$L_{reinf.}$ = 1.0 mm
$L_{reinf.}$ = 1.25 mm
$L_{reinf.}$ = 1.5 mm
$L_{reinf.}$ = 2.0 mm
Measurement error [%]
200
20
15
10
5
0
1
10
100
200
$E_{material}$ [GPa] , 201

Fig. 15

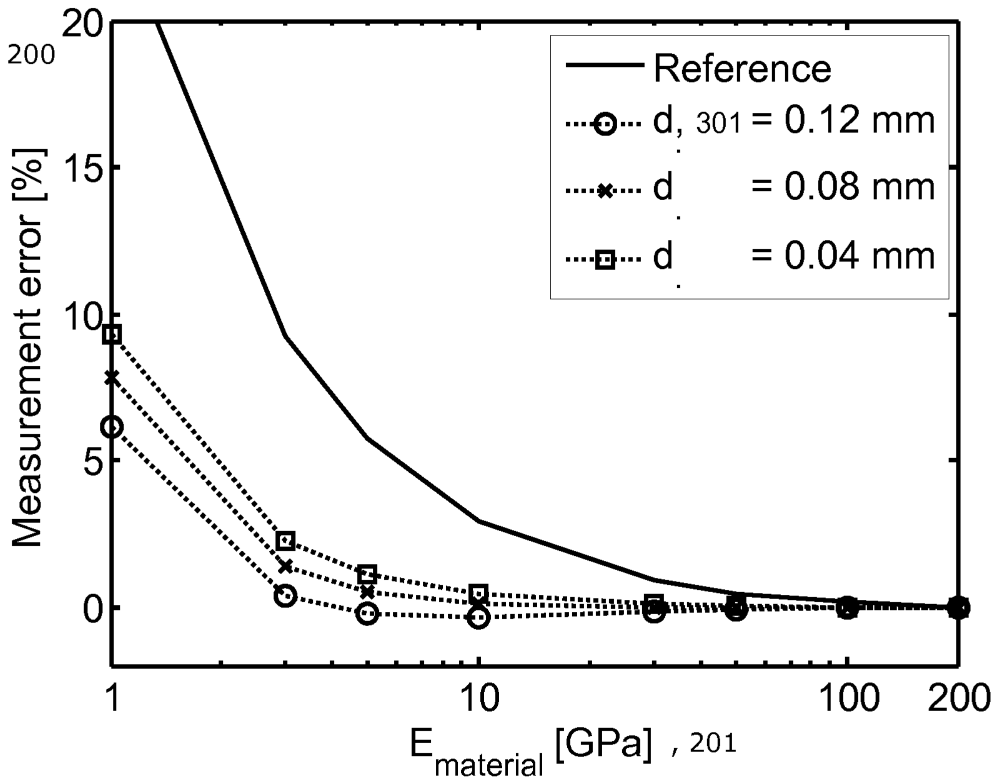


Fig. 16

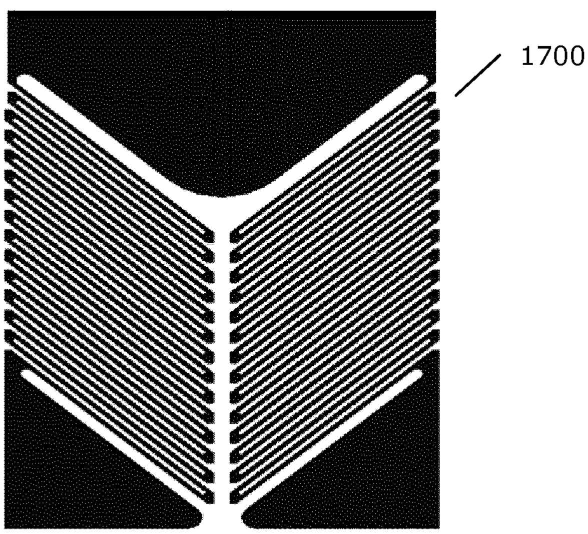


Fig. 17 (prior art)

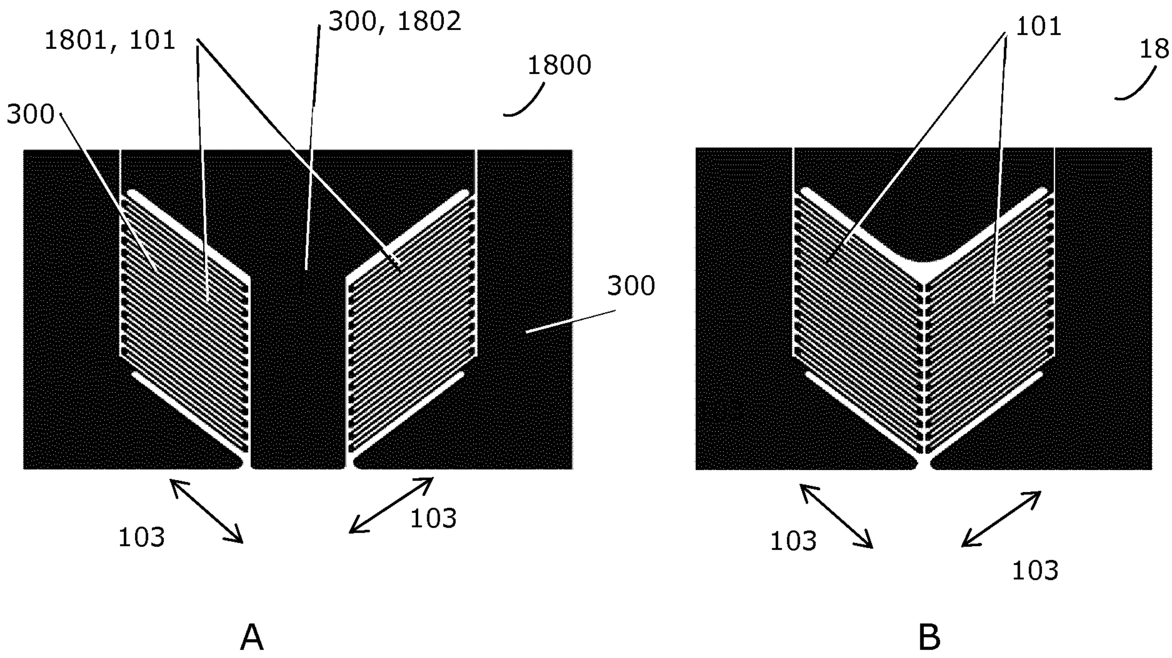

1801, 101
300, 1802
1800
300
300
103
103
A
101
1800
103
103
B

Fig. 18

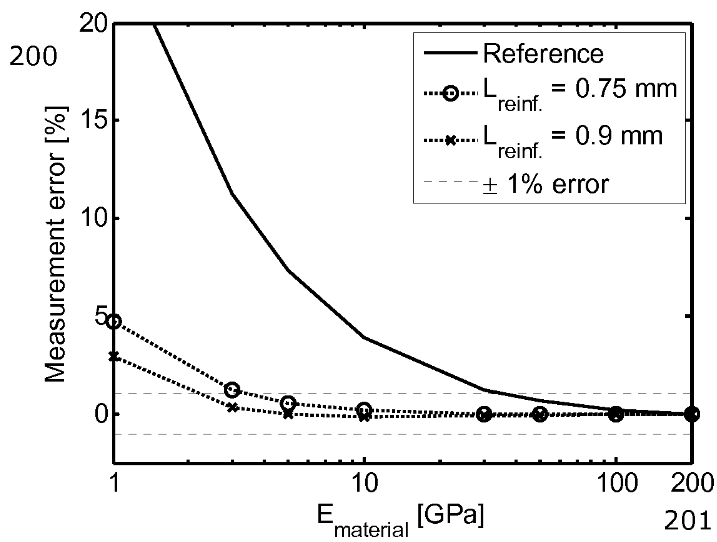

200
Reference
L reinf. = 0.75 mm
L reinf. = 0.9 mm
± 1% error
Measurement error [%]
20
15
10
5
0
1
10
100
200
E material [GPa]
201

Fig. 19

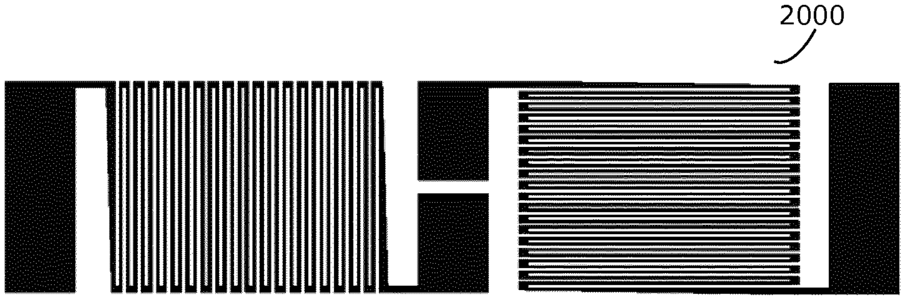


Fig. 20 (prior art)

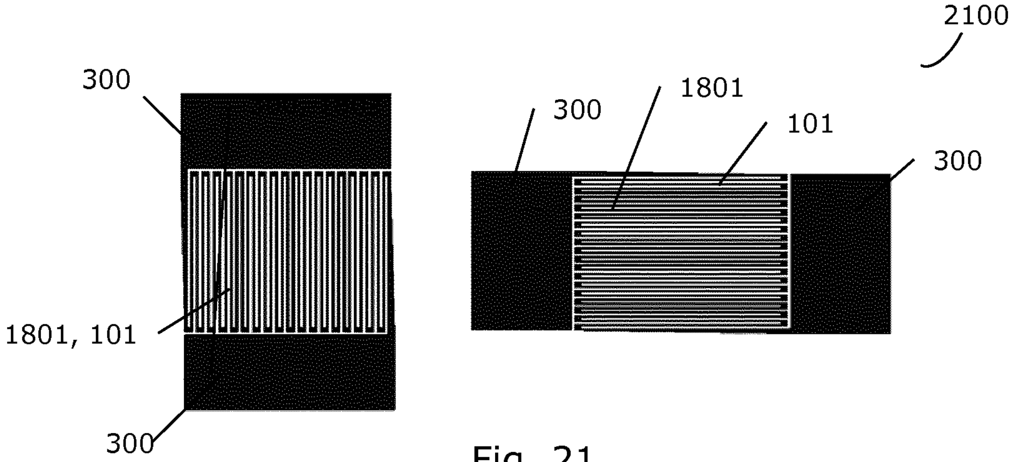
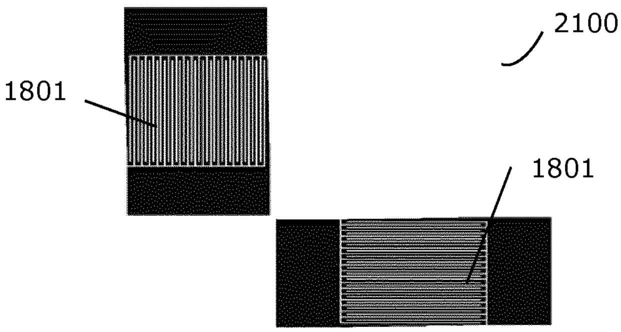


Fig. 21



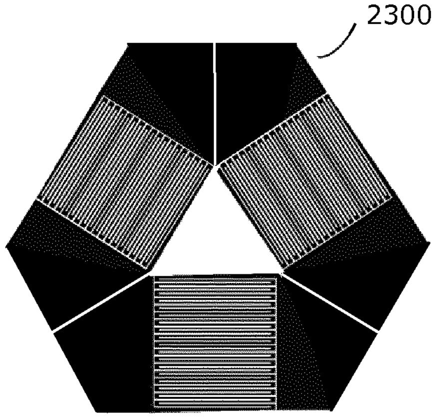


Fig. 22

Fig. 23

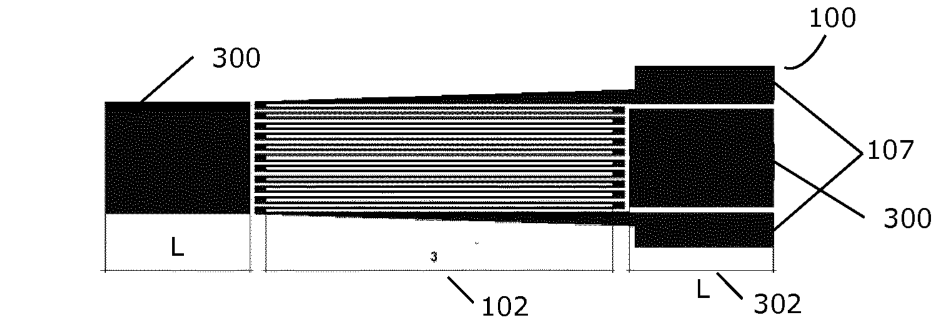


Fig. 24

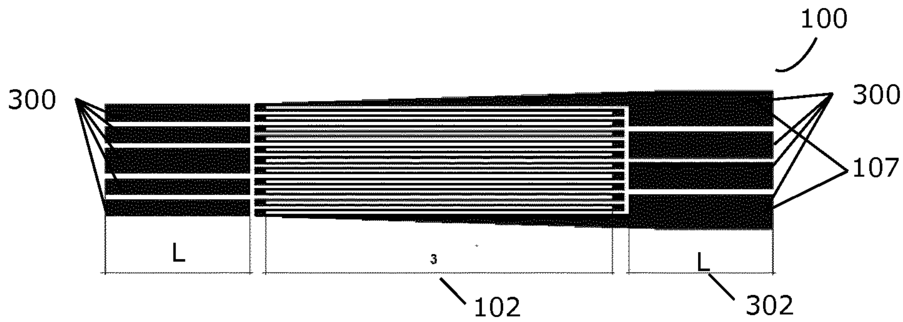


Fig. 25

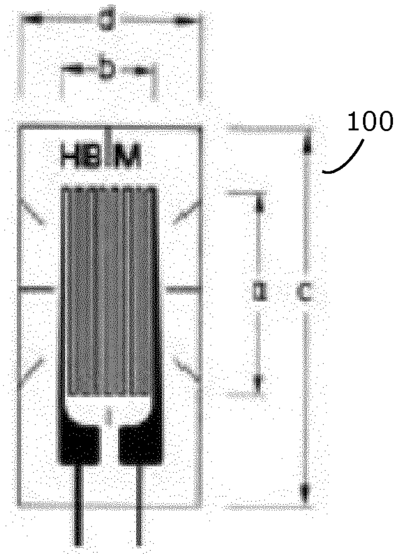


Fig. 26A

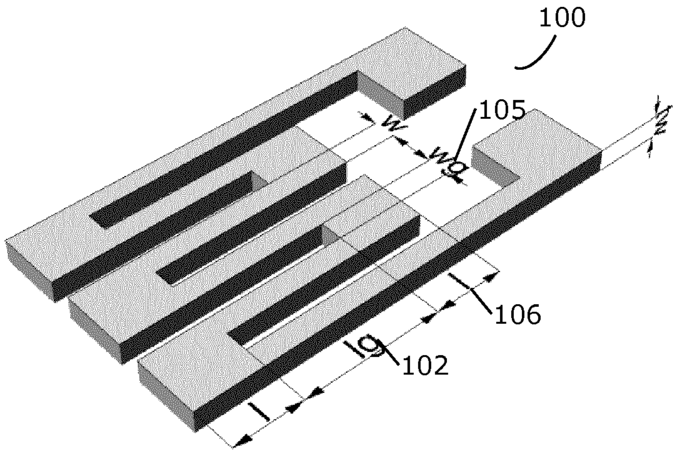


Fig. 26B

S.G. Type	a [mm]	b [mm]	c [mm]	d [mm]	Grid [mm]	Foil [mm]
1-LY11-1.5-/350	1.5	1.2	6.5	4.7	0.005	0.045
1-LY11-3-/350	3	1.6	8.6	4.5	0.005	0.045
1-LY11-10-/350	10	4.6	18.5	9.5	0.005	0.045

Fig. 27

S.G: Type	Grid spacing [mm]	Wired width [mm]	End-Loops length [mm]
1-LY11-1.5-/350	0.03	0.02	0.07
1-LY11-3-/350	0.03	0.03	0.1
1-LY11-10-/350	0.1	0.08	0.3

Fig. 28

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/066042

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L1/22 G01L1/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01L G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	GB 2 183 051 A (SEDEME) 28 May 1987 (1987-05-28) the whole document -----	1-11, 13-16,20 12
X A	JP S56 175705 U (UNKNOWN) 25 December 1981 (1981-12-25) figures 4,5,6,7 -----	1-11, 15-20 12
A	DE 102 60 577 A1 (GWT GLOBAL WEIGHING TECHNOLOGI [DE] SARTORIUS HAMBURG GMBH [DE]) 8 July 2004 (2004-07-08) figure 1 -----	11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2015	23/09/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kister, Clemens

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/066042

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